Movement Patterns of Hawaiian Petrels and Newell's Shearwaters on the Island of Hawai'i[1]

Robert H. Day,[2] *Brian A. Cooper,*[3] *and Richard J. Blaha*[3]

Abstract: We studied movements and distribution and abundance of endangered Hawaiian Petrels ('Ua'u [*Pterodroma sandwichensis* Ridgway]) and threatened Newell's Shearwaters ('A'o [*Puffinus auricularis newelli* Henshaw]) on the island of Hawai'i in May–June 2001 and 2002. We recorded radar targets of either species at 14 of the 18 sites but recorded no birds visually at any site. Movement rates of petrels and shearwaters were very low (0–3.2 targets per hour) over all except one of the sites (Waipi'o Valley: 25.8 targets per hour). We saw radar targets moving from shortly after sunset throughout the rest of the sampling, suggesting that both petrels and shearwaters were present. Highest movement rates occurred 1–2 hr after sunset, when primarily Newell's Shearwaters are flying. Timing of evening movements suggests that Hawaiian Petrels fly over the northern and southern parts of the island and may dominate on Mauna Loa and Mauna Kea. In contrast, timing suggests that Newell's Shearwaters fly over essentially the entire island (except in the southwestern part, where no birds appear to occur), dominate numerically in the Kohala Mountains, and occur in low numbers on Mauna Loa, in the Puna District, and on the northern slopes of Mauna Kea. Evening flight directions were predominantly inland at all sites except four. The limited radar data suggest that a substantial population change did not occur in the Puna District from 1995 to 2001–2002.

With the exception of the island of Kaua'i, little information is available on the distribution, abundance, and population trends of the endangered Hawaiian Petrel ('Ua'u [*Pterodroma sandwichensis* Ridgway]) and the threatened Newell's (Townsend's) Shearwater ('A'o [*Puffinus auricularis newelli* Henshaw]) in the Hawaiian Islands. This dearth of basic biological information is due primarily to these birds' nocturnal habits and the inaccessibility of their remote, mountainous nesting colonies. Obtaining accurate information on distribution, abundance, and population trends is an objective of the Recovery Plan for both species (USFWS 1983) and is especially important because of the recent, precipitous declines of Newell's Shearwaters on Kaua'i: in 2001, the number of shearwaters and petrels recorded on ornithological radar around this island averaged only 38–40% of that recorded in June 1993 (Day et al., in press).

The Hawaiian Petrel formerly was common on the island of Hawai'i (Wilson and Evans 1890–1899). This seabird reportedly nested in large numbers on the slopes of Mauna Loa, in the saddle between Mauna Loa and Mauna Kea, and at moderate to high elevations on Hualālai (Wilson and Evans 1890–1899, Henshaw 1902, Richardson and Woodside 1954). For example, Munro saw one on the ground in 1891 at ~1370 m

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[2] ABR, Inc.—Environmental Research & Services, P.O. Box 80410, Fairbanks, Alaska 99708-0410 (phone: 907-455-6777; fax: 907-455-6781; E-mail: bday@abrinc.com).

[3] ABR, Inc.—Environmental Research & Services, P.O. Box 249, Forest Grove, Oregon 97116-0249.

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(4500 ft) in Hōnaunau, Kona District (Banko 1980*a*). The Hawaiian Petrel was a food source of the ancient Hawaiians, and bones of this species are common in middens excavated in numerous locations on the island of Hawai'i (Banko 1980*a*). By the beginning of the twentieth century, however, a decline in this species had been noted by local residents, and, by the early 1940s, Munro (1960) feared for its survival in the Hawaiian Islands. However, this species still nests in low numbers at higher elevations of Mauna Loa (Simons and Hodges 1998, Hu et al. 2001), if not elsewhere on the island.

The Newell's Shearwater was thought to be extinct in the Hawaiian Islands after 1894. In 1954, however, a specimen was collected on O'ahu (King and Gould 1967), and a breeding colony was found on Kaua'i in 1967 (Sincock and Swedberg 1969). Newell's Shearwater also breeds on the island of Hawai'i, but probably in extremely low numbers: a few small nesting colonies recently have been found in cinder cones in the Puna District of eastern Hawai'i (Reynolds and Richotte 1997). This species nests primarily in burrows excavated under thick vegetation, especially uluhe fern (*Dicranopteris linearis* [Ainley et al. 1997]).

Reasons for the declines of both species are numerous. Introduced predators include wild pigs (*Sus scrofa*), Indian mongooses (*Herpestes auropunctatus*), feral cats (*Felis catus*) and dogs (*Canis familiaris*), Barn Owls (*Tyto alba*), Common Mynas (*Acridotheres tristis*), and Norway (*Rattus norvegicus*), black (*R. rattus*), and Polynesian (*R. exulans*) rats, all of which prey on both species, their eggs, and/or nestlings; in addition, introduced feral goats (*Capra hircus*) trample nesting colonies, and endemic Short-eared Owls (*Asio flammeus sandwichensis*) kill adults (Richardson and Woodside 1954, Sincock and Swedberg 1969, Byrd 1979, Byrd and Telfer 1980, Conant 1980, Byrd and Moriarty 1981, USFWS 1983, Simons 1984, 1985, Simons and Hodges 1998, Ainley et al. 2001, Hodges and Nagata 2001). Avian malaria and avian poxviruses from introduced birds also may have negatively affected populations of both species, particularly in low-elevation populations (Sincock and Swedberg 1969, USFWS 1983, Simons 1985). A secondary threat to these two species is their grounding (either through collision or exhaustion) and subsequent mortality during the annual fallout of birds, primarily juvenile Newell's Shearwaters that are on their way to the sea for the first time (Hadley 1961, Telfer 1979, Sincock 1981, Reed et al. 1985, Telfer et al. 1987, Cooper and Day 1998, Podolsky et al. 1998, Ainley et al. 2001). Predation by introduced mammals, however, is thought to be the primary cause of decline of both species on most islands and is considered to be the major threat to the surviving populations at this time (USFWS 1983, Simons and Hodges 1998, Ainley et al. 2001).

Ornithological radar, combined with visual sampling, is useful for studying the movements and behaviors of these two species of nocturnal seabirds and is especially useful in monitoring their populations. This research tool, which has been used in the Hawaiian Islands since 1992, has enabled much to be learned about the basic movements, behavior, distribution, and/or population trends of these species around Kaua'i (Cooper and Day 1995, 1998, Day and Cooper 1995, Day et al., in press), Maui (Cooper and Day in press), and Hawai'i (Reynolds et al. 1997; B.A.C. and R.H.D., unpubl. data). Most is known about movements of these species on Kaua'i and Maui.

Because of the recent declines of Newell's Shearwaters on Kaua'i and the potential for continued development on all of the main Hawaiian Islands, there is a clear need for basic information on the distribution, abundance, and movement patterns of petrels and shearwaters on all of the Hawaiian Islands. This study summarizes the results of radar surveys for Hawaiian Petrels and Newell's Shearwaters on the island of Hawai'i during May–June 2001 and 2002.

Study Area

Hawai'i is the largest and easternmost of the main Hawaiian Islands. It is ~130 km (~81 miles) in an east-west direction and ~145 km (~90 miles) in a north-south direction and has a total area of ~10,410 km^2 (~4021 square miles). The island is dominated by four mountains: the enormous Mauna Loa (4170 m [13,679 ft] high) in the southern part of the island, Mauna Kea (4206 m [13,796 ft]) in the northeast, Hualālai (2522 m [8271 ft]) in the west, and the Kohala Mountains (1671 m [5480 ft]) in the northwest. Mauna Loa, Mauna Kea, and Hualālai are classic shield volcanoes, whereas the Kohala Mountains are characterized by numerous steep valleys on their northern sides, much like northern Kaua'i. Habitats range from palm trees at sea level to rain forest (on windward slopes) or xeric/mesic shrubs (on leeward slopes) at moderate elevations and to snow and alpine vegetation near the summits of Mauna Loa and Mauna Kea.

MATERIALS AND METHODS

We collected data on the movements of Hawaiian Petrels and Newell's Shearwaters at 15 sites between 31 May and 15 June 2001 and at three additional sites between 14 and 22 June 2002. All sites were situated on the perimeter of the island, as close as possible to the ocean. Sites were selected to provide both synoptic coverage of a region and information on individual locations (e.g., Waipi'o Valley) that were likely concentration points for inland flights of petrels and shearwaters.

We sampled with ornithological radar for 3 hr/night, between 1900 and 2200 hours in the evening; this part of the evening includes the peak of inland movement of these birds toward their nesting colonies (Day and Cooper 1995). We attempted to collect data during 25-min sessions, then used 5-min breaks between periods of data collection to collect weather data and to give observers a short break. Actual lengths of sampling sessions were 14–25 min for radar data (some time was lost when precipitation obscured the radar screen), with 97 of 108 sampling sessions being the full 25 min long. We were unable to sample at all during two 25-min sessions (one at Kona and one at Maulua Stream). At the beginning of each sampling session, we recorded weather data, light conditions (daytime, crepuscular [twilight], darkness), and moon phase/presence (i.e., whether the moon was above or below the horizon). When a volunteer was available (11 of the 21 nights), we also conducted visual sampling (10× binoculars or 5× Noctron night-vision scope) for species identifications and flight altitudes.

Data Collection

We collected information on flying birds with a Furuno FCR-1510 MKIII (in 2001) or a Furuno FCR-1411 (in 2002) surveillance radar, which was an X-band radar transmitting at 9410 MHz with a peak power output of 12 kW (10 kW for the FCR-1411). The range of this radar was set at 1.5 km (1.4 km for the FCR-1411), the pulse setting was 0.07 μsec (0.08 μsec for the FCR-1411), and the plotting function was set to "continuous" (every 15 sec for the FCR-1411). A similar surveillance radar is described in Cooper et al. (1991). The radar scanned a 360° arc around the mobile radar laboratory and was used to obtain information on movement rates, flight paths, and ground speeds of birds. This radar has a digital color display with several scientifically useful features, including color-coded echoes (to differentiate the strength of return signals), on-screen plotting of a sequence of echoes (to depict flight paths), and True North correction for the display screen (to determine flight directions easily). (An echo is a picture of a target on the radar display screen; a target is one or more birds displayed as a single echo on the radar display screen.) The plotting function plotted the location of a target every sweep of the antenna; because time intervals are fixed, ground speed is directly proportional to the distance between consecutive plots and can be measured with a hand-held scale. We minimized ground clutter by elevating the forward edge of the antenna, using a ground-clutter reduction screen mounted to the bottom of the antenna face (described in Cooper et al. 1991), and positioning the radar so that nearby vegetation acted as a radar fence (see Eastwood 1967).

For each echo seen on the radar display

screen, we recorded time, flight direction (to the nearest 1°), and flight velocity (to the nearest 8 km/hr [5 mi/hr]). We collected data only on targets flying ≥48 km/hr (≥30 mi/hr) and over land (following Day and Cooper 1995, Day et al., in press). We also included targets flying <48 km/hr (<30 mi/hr) that we identified visually as being of either of the two species of interest and excluded targets flying the appropriate speed but of another species; during this study, we added no petrel or shearwater targets flying <48 km/hr and excluded no targets of other species that were flying the appropriate speed. Although we attempted to collect information on species identification, flock size, and estimated flight altitude of birds at 11 of the 18 sites, we had no visual sightings of either species in 2001 or 2002.

Data Analysis

All statistical analyses were conducted with SPSS or Microsoft Excel software. We tabulated numbers of targets recorded during each sampling session, then converted these counts to estimates of movement rates (targets per hour), based on the number of minutes sampled. Because rain showers sometimes obscured substantial portions of the screen, we subtracted that time from the 25-min sampling period and used the resulting time in the calculation of movement rates. We used the estimated movement rates for each sampling period to calculate the mean ± 1 standard error (SE) movement rate for each night's sample and used the flight-direction data to calculate the mean flight direction for each night's sample. At the Pa'auilo site in 2002, we had four consecutive nights of movement data, so we calculated the mean movement rate and mean flight direction over the four nights at that site; otherwise, all other sites had only one night of data. To calculate flight directions, we converted flight directions to radians and calculated the mean direction following Zar (1984).

At each site, we used data on the timing of movements of these two species on Kaua'i with respect to sunset and the point of complete darkness (Day and Cooper 1995) to estimate whether either species occurred there. Hawaiian Petrels on Kaua'i head inland from about sunset to a maximum of ~60 min after sunset; however, most are moving up to about the point of complete darkness (i.e., the end of twilight), which occurs ~30 min after sunset. In contrast, Newell's Shearwaters on Kaua'i head inland from about 30 min after sunset (i.e., shortly after the point of complete darkness) onward. Thus, the two species overlap in occurrence from the point of complete darkness to ~30 min afterward. We used these differences in timing on Kaua'i and assumed no interisland differences in relative timing to evaluate the species probably present at each site on Hawai'i. Probable Hawaiian Petrels occurred between sunset and the point of complete darkness, whereas probable Newell's Shearwaters occurred from ~60 min after sunset onward. Possible Hawaiian Petrels or possible Newell's Shearwaters occurred during this period of overlap in movement, between ~30 and ~60 min after sunset (i.e., from the point of complete darkness to ~30 min later). Hence, we assumed two competing scenarios for identity during this period of overlap in movement: (1) that all of the birds occurring during this period of overlap were Hawaiian Petrels; and (2) that all were Newell's Shearwaters.

RESULTS

During our sampling, sunset occurred between 1854 and 1900 hours, or just before we began sampling. Civil twilight ended (i.e., the point of complete darkness occurred) at 1919–1924 hours, or ~25 min after sunset. Nightly variation in cloud cover and in topography and aspect of a site, however, resulted in a 10- to 15-min range among nights in the timing of the point of complete darkness. In 2001, the sampling occurred from 2 days after the first quarter moon to 2 days after the third quarter; hence, it occurred during ~1 week on either side of the full moon. In 2002, the sampling occurred from midway between the new moon and the first quarter to midway between the first quarter and the full moon.

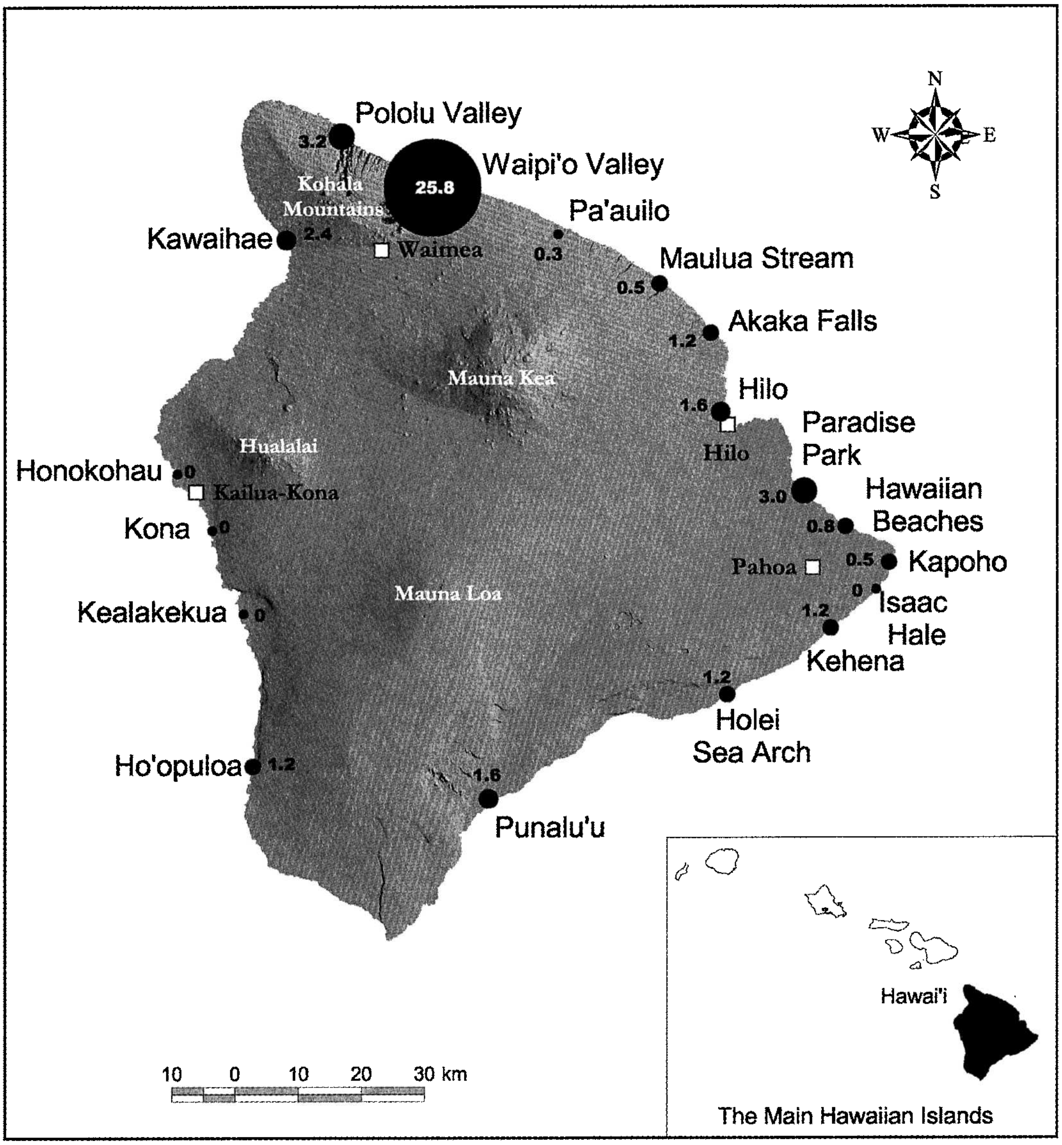

FIGURE 1. Geographic variation in movement rates (targets per hour) on surveillance radar around Hawai'i, May–June 2001 and 2002. Sizes of shaded circles are proportional to the rate of movement. White squares indicate location of towns.

Relative Abundance, Timing, and Species Identity

Very low numbers of petrels and shearwaters flew over all except one of the study sites (Figure 1). Mean nightly movement rates ranged from 0 to 25.8 targets per hour but exceeded 3.2 targets per hour at only one site (Waipi'o Valley). Further, bird targets were recorded at only 14 of the 18 sites, with none recorded at Isaac Hale, in southeastern Hawai'i, and at three sites in the southwestern part of the island—Honokōhau, Kona, and Kealakekua. The highest movement rates were observed at Waipi'o Valley, which is

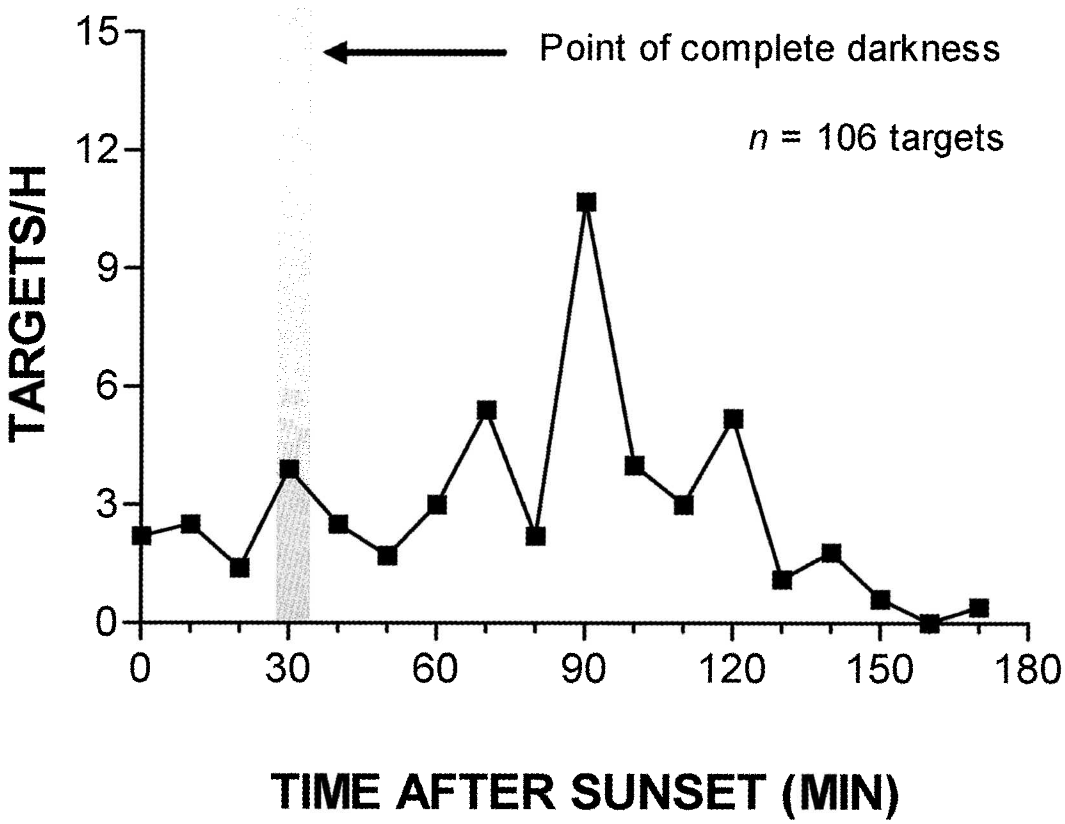

FIGURE 2. Evening pattern of movement of targets on surveillance radar at all study sites combined on Hawai'i, May–June 2001 and 2002, by time after sunset.

located on the wetter, windward coast of the island. No birds were observed visually at any of the sites.

Movement rates were variable within a night, although radar targets moved from shortly after sunset throughout the rest of the night (Figure 2). In general, the highest rates occurred ~1–2 hr after sunset, or ~30–90 min after the point of complete darkness. A smaller pulse of inland-heading movement also occurred ~30 min after sunset, or just at the point of complete darkness.

Based on the timing of inland movements, proportions of the two species varied among sites. The occurrence of targets between sunset and the point of complete darkness (Day and Cooper 1995) suggests that Hawaiian Petrels occurred at 7 of the 14 sites where we recorded radar targets (Kehena, Kawaihae, Pololū Valley, Maulua Stream, 'Akaka Falls, Hilo, and Paradise Park), formed 100% of the targets (i.e., occurred entirely during the period when only this species was moving) at one site (Maulua Stream), and may have formed 100% of the targets (i.e., assuming that all of the targets recorded during the period of overlap were of this species) at another three sites (Kehena, Punalu'u, and Hilo). The occurrence of targets >60 min after sunset suggests that Newell's Shearwaters occurred at 10 of the 14 sites where we recorded radar targets (Kapoho, Hōlei Sea Arch, Ho'ōpūloa, Kawaihae, Pololū Valley, Waipi'o Valley, Pa'auilo, 'Akaka Falls, Paradise Park, and Hawaiian Beaches), possibly occurred at another three sites during the zone of overlap (Kehena, Punalu'u, and Hilo), formed 100% of the targets at four sites (Kapoho, Hōlei Sea Arch, Pa'auilo, and Hawaiian Beaches), and may have formed 100% of the targets (i.e., assuming that all of the targets recorded during the period of overlap were of this species) at another two sites (Ho'ōpūloa and Waipi'o Valley). The data strongly suggest that Newell's Shearwaters were most abundant in Waipi'o Valley and the Kohala Mountains in general.

Overall, the geographic pattern suggests that the number of birds flying over the southwestern part of the island (in the vicinity of Hualālai) is so low as to approach zero. The timing of evening movements suggests that Dark-rumped Petrels fly over the northern and southern parts of the island and may dominate on Mauna Loa and Mauna Kea. In contrast, the timing suggests that Newell's Shearwaters fly over essentially the entire island (except in the southwestern part), dominate numerically in the Kohala Mountains, and occur in low numbers on Mauna Loa, in the Puna District, and on the northern slopes of Mauna Kea.

Flight Direction and Location

Evening flight directions were predominantly inland at all sites except Hōlei Sea Arch, Ho'ōpūloa, Pa'auilo, and 'Akaka Falls (Figure 3). In this figure, we have excluded sites where we recorded less than three flight directions. At Ho'ōpūloa and Hōlei Sea Arch, the few targets that we did record were heading seaward, but the mean flight direction paralleling the coast at Pa'auilo and 'Akaka Falls was an artifact of peculiarities of circular statistics and small sampling sizes (some targets heading seaward and some heading inland, resulting in a directional vector that was nearly at right angles to those directions).

DISCUSSION

Species Identity

Although we were unable to observe any of the birds visually to determine their identity, based on our previous studies on Kaua'i, Maui, and Hawai'i (Cooper and Day 1995, 1998, in press, Day and Cooper 1995, unpubl. data, Reynolds et al. 1997, Day et al., in press) and the timing of movements observed in this study, we believe that most radar targets were Newell's Shearwaters, with smaller numbers of Hawaiian Petrels. In the evening, Newell's Shearwaters on Kaua'i tend to head into the colonies after it becomes completely dark outside (Day and Cooper 1995, unpubl. data); similarly, nearly all of the birds observed in this study occurred after it became dark. Likewise, all of the (few) targets seen visually and identified to species in the Puna District and in Waipi'o Valley in 1994 were Newell's Shearwaters (Reynolds et al. 1997). Hence, most of the radar targets we observed at our study sites in 2001–2002 probably were Newell's Shearwaters, although it is likely that at least a few Hawaiian Petrels also flew over our sites, based on the predarkness timing of movements of birds at several sites and the fact that small numbers breed on Mauna Loa (Simons and Hodges 1998, Hu et al. 2001).

Distribution and Abundance

The low numbers of seabirds that we recorded flying inland at all sites except Waipi'o Valley match well with the limited information that is available on the distribution of Hawaiian Petrels and Newell's Shearwaters on the island of Hawai'i (Ainley et al. 1997, Reynolds et al. 1997, Simons and Hodges 1998; R.H.D. and B.A.C., unpubl. data). With the exception of Waipi'o Valley, some cinder cones in the Puna District of eastern Hawai'i, and some small colonies high on Mauna Loa and probably Mauna Kea, petrels and shearwaters are thought to be scarce on this island.

The distribution of the Hawaiian Petrel on the island of Hawai'i is imperfectly known but seems to match the pattern we saw in 2001–2002. We can find no definite records of this species within the Puna District for at least the last 30 yr, although our data for Paradise Park and Kehena suggest that a few fly over this area on their way inland. In the Ka'ū District, the species has been reported repeatedly in Hawaiian Volcanoes National Park (van Riper and Barbee 1978, Banko

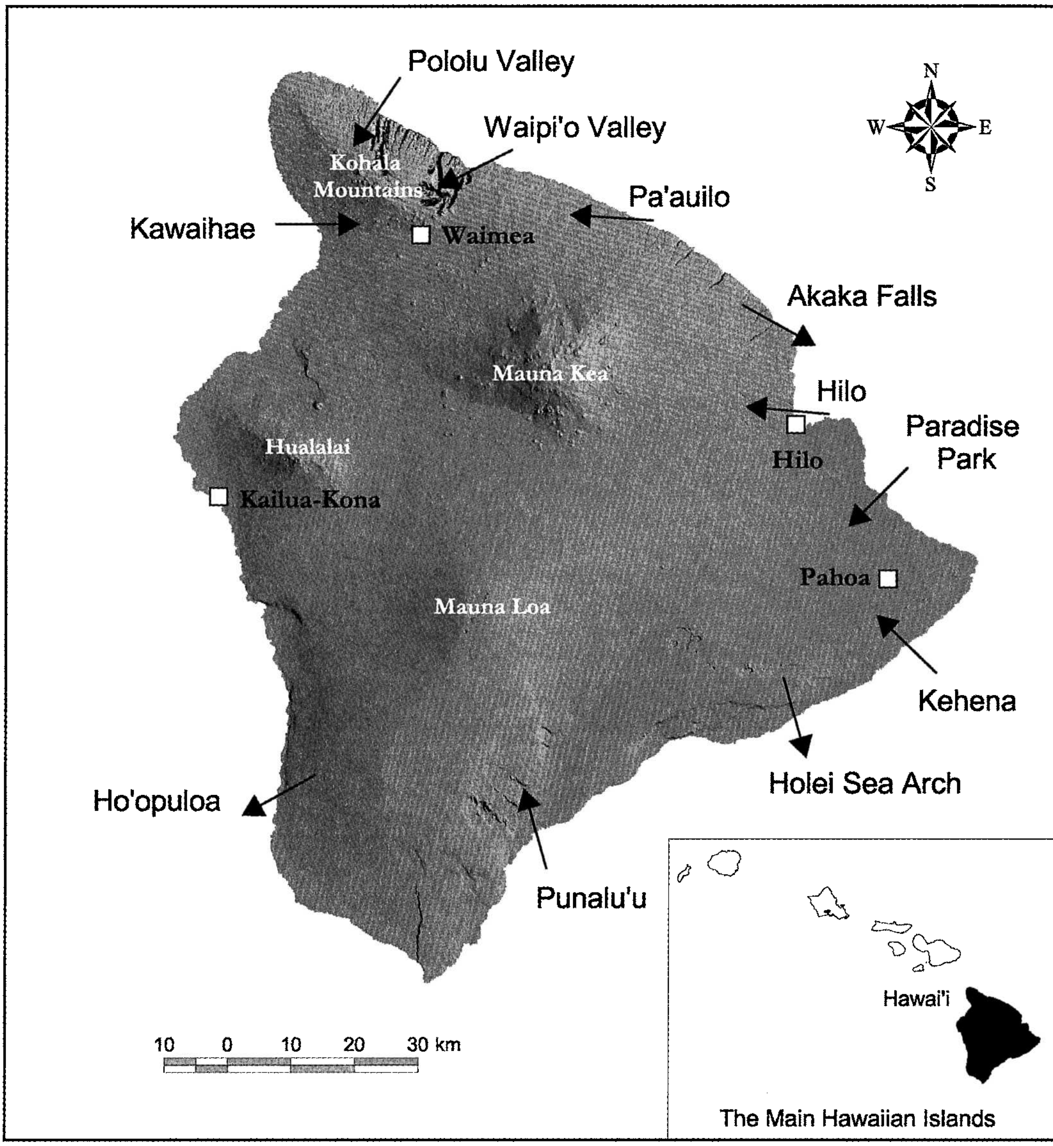

FIGURE 3. Mean flight direction of targets observed on radar around Hawai'i, May–June 2001 and 2002. Only sites with three or more targets are shown. White squares indicate location of towns.

1980*a*, Pyle 1984, 1986*c*) and on Mauna Loa (Banko 1980*a*, Conant 1980, Pyle 1992*b*, Hu et al. 2001; B.A.C. and R.H.D., unpubl. data); our data indicate that this species probably flew over Hōlei Sea Arch and Punalu'u. We can find no recent records of Hawaiian Petrels from the South Kona District; we recorded only a few possible petrels flying inland at Ho'ōpūloa but saw none at Kealakekua, suggesting that most reach Mauna Loa from a direction other than the southwest or west. In the North Kona District, the only recent record of this species that we can find is of calling birds on Hualālai in the 1970s

(Conant 1980); because a subsequent visit there failed to turn up any birds, the few that were recorded may have been passing farther inland to nesting areas on Mauna Loa. Similar to this apparent rarity, we recorded no petrels (or shearwaters) at Kona or Honokōhau. There also are no recent records of Hawaiian Petrels from either the South Kohala or North Kohala (plus Waipi'o Valley) Districts (i.e., the Kohala Mountains); however, our data for Kawaihae and Pololū Valley and probably Waipi'o Valley suggest that petrels nest somewhere in those mountains in low numbers. The species formerly nested, and probably still does, somewhere on Mauna Kea, given the number of both old and recent records from there and the Hāmākua and North Hilo Districts (Richardson and Woodside 1954, Banko 1980*a*, Pyle 1986*a,b*, 1992*a*); likewise, our data indicate that petrels fly over both Maulua Stream and 'Akaka Falls on their way inland. We found historical (Baldwin and Hubbard 1949), but no recent, records of Hawaiian Petrels in the South Hilo District; however, our data indicate that the species passes over the Hilo area while heading inland.

The Newell's Shearwater has been recorded in numerous locations on the island of Hawai'i, although information on exact nesting locations is limited. In the Puna District, the species recently has been found to nest in at least one cinder cone (Reynolds and Richotte 1997), and numerous visual and radar records (Pyle 1986*a*, 1992*b*, Reynolds et al. 1997; R.H.D. and B.A.C., unpubl. data) suggest regular, albeit low-level, use of the area. The one exception was a stream of Newell's Shearwaters seen flying inland in the "Kalapana district" over an "extended period" in the summer of 1992 (Pyle 1992*b*). In this district, we recorded this species at Paradise Park, Hawaiian Beaches, and Kapoho and possibly at Kehena (some targets occurred during the zone of overlap of the two species), but not at Isaac Hale, suggesting presence but low overall abundance. In the Ka'ū District, information on the species' distribution and abundance is unclear. The species was recorded breeding in Makaopuhi Crater (southeast of Kīlauea Caldera) in 1972 (Kepler et al. 1979); however, Banko (1980*b*) recorded none afterward, and the recent records on ornithological radar from the national park (Reynolds et al. 1997) are of questionable accuracy (see later in this discussion). Elsewhere in the Ka'ū District, these shearwaters are believed to nest at moderate elevations on the southeastern slopes of Mauna Loa (R. E. David, Kailua-Kona, pers. comm.), a belief strengthened by our data from Hōlei Sea Arch and possibly Punalu'u; however, B.A.C. (unpubl. data) did not record them visually in the Pōhakuloa Training Area or farther up on Mauna Loa in 1995 (no radar sampling was possible because of the presence of large numbers of nocturnal insects), suggesting that, if they nest on Mauna Loa, they do so only in low numbers and/or at moderate elevations on that mountain's steep southeastern slopes. In the South Kona District, the only records we can locate are a specimen and several records of Newell's Shearwaters heard calling at night as they flew over the Pāpā area between 1970 and 1972 (Banko 1980*b*); our data from Ho'ōpūloa indicate that Newell's Shearwaters still use this area, although their absence from Kealakekua suggests that they are rare there. We can find no recent or historical records of this species from the North Kona District, and our data suggest that the species is absent from or occurs in very low densities in that district. We also can find no recent or historical records of this species from the South Kohala District, but, in the North Kohala District (plus Waipi'o Valley), the species must nest in at least one location, and probably more, in the Kohala Mountains; in particular, the species must nest in substantial numbers somewhere up Waipi'o Valley, as indicated by the large number of visual (Hall 1978, Kepler et al. 1979, Reynolds et al. 1997) and radar (Reynolds et al. 1997; this study) records from that location. The species also must nest somewhere on the northern slopes of Mauna Kea, given the substantial number of records from the Hāmākua, North Hilo, and South Hilo Districts (Ralph and Pyle 1977, Kepler et al. 1979, Banko 1980*b*, Conant 1980, Pyle 1990, 1998); similarly, our data suggest that this species occurred at Pa'auilo, 'Akaka Falls, and Hilo. In this part of the island, the most promising additional sites for this species include the vicinity of 'Āwehi Stream, Ka'uku Hill, Hakalau Stream, and the Wailuku River.

Population Trends

Although our overall pattern of abundance was similar to that from other studies, the movement rates that we observed at Waipi'o Valley and in the Puna District of eastern Hawai'i in 2001–2002 were lower than those observed by Reynolds et al. (1997) in 1994. In contrast, our results in 2001–2002 were similar to those in a study at Kehena in 1995 (B.A.C. and R. E. David, unpubl. data) and a study in the Puna District in 2001 (unpubl. data).

We conclude that the Reynolds et al. (1997) estimates are not comparable with those in this or any other study and that the identity of some of their radar targets should be considered questionable. The data upon which the 1994 estimates were based are extremely limited at best, they were collected only during the peak of movement (inflating estimates of mean movement rates over an evening), some were collected during a period (morning) in which the estimates would be inflated because that period of peak movement is shorter and more intense than that in the evening, and some of the data almost certainly were of insects (especially at places such as Pali Uli), rather than birds, or were birds of other species. In the study reported here, some insect contamination also is possible for the Waipi'o Valley site, where we observed hundreds of targets in 2001 flying just below the 30 miles/hr cutoff speed. It is possible that these were petrels or shearwaters flying slowly against a headwind that was not apparent on the ground (on the ground, we recorded an easterly tailwind, which would have increased the velocity of organisms flying westward), but our best guess is that these slow targets primarily were large moths traveling with a tailwind and/or smaller seabirds such as Black Noddies (*Anous minutus*) or Sooty Terns (*Sterna fuscata*). Unfortunately, we were unable to obtain any visual identifications of birds while sampling at that site in 2001; however, Reynolds et al. (1997) did visually identify four Newell's Shearwaters and one unidentified shearwater/petrel, but no Black Noddies or Sooty Terns, at Waipi'o Valley in 1994, indicating that at least some of their targets were correctly identified.

In contrast to the pattern seen for the 1994 Reynolds et al. (1997) study, July 1995 data both from and near the Kehena site averaged ~0.4 targets per hour across four nights and mornings of sampling (B.A.C. and R. E. David, unpubl. data), or slightly lower than what we saw in this study. These data are more comparable (i.e., collected and analyzed similarly) with those from this study and suggest that there has not been a substantial decline in the number of petrels and shearwaters visiting the Puna District between 1995 and 2001–2002.

During fall 2001, we (unpubl. data) also collected and analyzed data in the Puna District similarly to what we did in this study. We recorded means of 1.5 targets per hour at Kehena, 0.8 targets per hour at Isaac Hale, 0.4 targets per hour at Kapoho, 0.4 targets per hour at Hawaiian Beaches, and 1.2 targets per hour at Paradise Park. Hence, these recent fall data also are similar to the pattern reported here for the Puna District in summer 2001–2002.

Comparison with Other Islands

This study indicates that the number of Hawaiian Petrels and Newell's Shearwaters visiting the island of Hawai'i is fairly small, probably on the order of a few thousand birds. At most locations we sampled, movement rates were low, ranging between 0 and ~3 targets per hour, suggesting that 0–10 birds flew over each site in the first 3 hr of the evening. Obviously, the number of birds visiting the Kohala Mountains is considerably larger, with probably several hundred flying up Waipi'o Valley and the two similar valleys immediately to the west of it and others coming in along the rest of the coastline in that area.

Mean evening movement rates at all locations on Hawai'i except Waipi'o Valley were much lower than those at all sites examined on Kaua'i (Day and Cooper 1995, Day et al., in press) and were comparable to those at the lowest-movement sites on southwestern Maui (Cooper and Day in press). Clearly, however, the mean movement rate at Waipi'o Valley was comparable to some on the eastern shore of Kaua'i and with moderate-movement sites on Maui. The pattern of higher movement rates on the wetter, windward side of Hawai'i in this study follows those from these other two islands, where rates also are higher on the wetter, windward sides and lower on the drier, leeward sides of the islands.

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